Early deafness is thought to affect low-level sensorimotor processing such as selective attention, whereas bilingualism is thought to be strongly associated with higher order cognitive processing such as attention switching under cognitive load. This study explores the effects of bimodal-bilingualism (in American Sign Language and written English) on attention switching, in order to contrast the roles of bilingual proficiency and age of acquisition in relation to cognitive flexibility among deaf adults. Results indicated a strong high-proficiency bilingual advantage in the higher order attention task. The level of proficiency in 2 languages appears to be the driving force for cognitive flexibility. However, additional data are needed to reach conclusive interpretation for the influence of age of second language acquisition on higher order attention-switching ability and associated cognitive flexibility.

Visual selective attention and attention switching differ in their representational nature. Visual selective attention is thought to be more reliant on low-level sensorimotor processing, whereas attention switching is strongly associated with higher order cognitive processing. As low-level sensorimotor and visual functions mature, neural networks for higher order cognitive functions are built upon these foundations and subsequently emerge later in life (Gogtay et al., 2004). However, early deafness may affect the cortical organization for low-level perceptual processes such as visuospatial attention or the associated neural network that facilitates newborn neural development. Specifically, differences in early sensory experience appear to influence allocation of visual attention to the peripheral field among deaf individuals as compared to hearing individuals (Bavelier et al., 2001; Bosworth & Dobkins, 2002; Loke & Song, 1991; Neville & Lawson, 1987a, 1987b; Parasnis & Samar, 1985; Proksch & Bavelier, 2002), but not the mechanisms of attention efficiency for alerting and orienting (Dye, Baril, & Bavelier, 2007) or simultaneous visual processing of multiple objects (Hauser, Dye, Boutla, Green, & Bavelier, 2007). When the individual is required to use endogenous attention to rapidly switch from one visual field to another visual field, higher order cognitive processing is activated. An important part of higher order cognitive processing is that it reduces burden on the frontal lobe and increases efficiency for attentional flexibility. Additionally, higher order cognitive ability appears to be enhanced by bilingual experience (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Ryan, 2006).

According to a code-switching theory (Peal & Lambert, 1962), switching between languages provides the bilingual individual with a higher degree of mental flexibility and concept formation. This cognitive advantage may be based on use of inhibitory functions of the frontal lobe such that interference from another language is inhibited and one can selectively attend to the language that is currently in use (Green, 1998). Data from a case study on bilingual patient with a frontal lesion as well as functional neuroimaging study of normal bilinguals suggest that the anterior cingulate and dorsolateral prefrontal regions are intimately

*Correspondence should be sent to: Poorna Kushalnagar, Department of Health Services, University of Washington, Seattle, WA 98195 (e-mail: poornak@u.washington.edu).
involved in switching between two languages (Fabbro, Skrap, & Aglioti, 2000; Hernandez, Dapretto, Mazzotta, & Bookheimer, 2001; Hernandez, Martinez, & Kohnert, 2000). These regions were also identified consistently as important for shifting attention function in a meta-analysis study across 31 positron emission tomography and functional magnetic resonance imaging (fMRI) studies (Wager, Jonides, & Reading, 2004). This analysis also concluded that neural activation during tasks requiring location shifting (switching attention to targets from one location to another location) was associated with significantly more activity in the right premotor and intraparietal sulcus regions.

Behavioral studies of bilingualism and attention have provided additional support for neuropsychological and neuroimaging findings on the beneficial effects of bilingualism on frontal lobe functioning. For example, Bialystok, Craik, Klein, and Viswanathan (2004) found that complex attention performance under a cognitive load among bilingual adults exceeded that of the same-age monolingual adults. The cognitive benefits associated with bilingual proficiency persist through old age (Bialystok, Craik, & Ryan, 2006). In a study with children, Yang (2007) reported higher performance among bilinguals compared to monolinguals on an attention network test that involves several aspects of executive control and attention shifting skills. The continuous involvement of several neural areas in the frontal regions for language and attention switching affords an opportunity to strengthen higher order neurocircuitry within the frontal cortex, providing a bilingual individual with an attention network system advantage. Interestingly, this bilingual advantage appears to extend to nonlinguistic domains. As such, we propose that (a) low-level sensorimotor development associated with selective attention is constant across early deafness and (b) higher order cognitive development for attention switching is driven by distinct bilingual experience. We expect that deaf people will perform similarly on selective attention tasks, but may show variation on attention-switching task due to bilingual proficiency level.

Empirical studies on bilingualism and cognition thus far have been limited to participants whose hearing ability falls within normal limits. Recent research suggests that the cognitive advantage associated with bilingualism is specific to languages that share output modalities (e.g., spoken English and Spanish). When a bimodal-bilingual user simultaneously uses two languages with different output modalities (e.g., spoken English and American Sign Language [ASL]), neither language is actively suppressed, as compared to bilingual speakers who can only use one spoken language at a time. In a recent study by Emmorey, Luk, Pyers, and Bialystok (2008), 15 hearing adults who are accustomed to speaking English while signing in ASL at the same time (bimodal-bilingual users) did not differ from 15 monolinguals (one spoken language) in performing a task requiring inhibition and mental flexibility. The authors argued that this is a consequence of simultaneous use of two different language output modalities such as spoken and signed language. This appears to promote development of a distinct neural system that permits simultaneous use or merging of these two languages, unlike using two spoken languages consecutively, which requires suppression or inhibition of one language during utilization of the other language.

Emmorey et al. (2008) proposed that deaf people who are users of two same-modality signed languages (e.g., ASL and British Sign Language) should demonstrate similar cognitive benefits to those observed in dual spoken-language bilinguals. However, the majority of deaf Americans use ASL as the only signed language. They are able to read and write English, ranging from low to high fluency. Some of these individuals may not produce clear speech production that may mislead hearing people to perceive that they are also not fluent in reading and writing English. If an individual is highly fluent in reading and writing English, then this individual is considered proficient in this language even if his/her speech production is unclear. Such an individual may be considered to be bimodal-bilingual in that he/she is able to read English and use ASL. However, it is unlikely that this individual will simultaneously speak in English and use sign language at the same level as hearing bimodal-bilingual users in the study by Emmorey et al. Additionally, it is not possible to simultaneously communicate in both modalities (sign and write). The effect of these differences on the cognition of deaf Americans who are proficient English readers and proficient ASL signers has not been explored. It is essentially “uncharted territory.” We attempted to determine whether high proficiency in ASL and written English provide
deaf individuals with the advantage that is frequently observed in hearing bilinguals of two spoken languages.

Given the above points, it may be logical to expect that deaf Americans who are proficient in “both” signed and written languages would demonstrate better cognitive control and mental flexibility abilities than deaf Americans who demonstrate high proficiency in one language but lower proficiency in another language. English and ASL were found to utilize the classical language regions in the left-hemisphere brains of hearing speakers of English and deaf people who are fluent users of ASL (Neville et al., 1998). Deaf people who are highly proficient in written English and ASL should also display the cognitive advantages associated with bilingualism that was observed in studies of hearing bilinguals reviewed in this study. Thus, the level of bilingual proficiency is likely to play a significant role in higher order cognitive processing such as attention switching and executive control rather than low-level perceptual processing such as selective attention.

This article was designed to examine the effects of bilingualism on switching attention between central and peripheral visual stimuli among deaf adults. If bilingualism provides the individual with an advantage on tasks that require involvement of the cognitive control network, then we expect to find that deaf bilinguals who have high proficiency in both languages (balanced bilinguals) will significantly outperform low-proficient deaf bilinguals (unbalanced bilinguals) on a higher order attention-switching task. However, group differences are not expected on low-level selective attention tasks that do “not” require shifting attention from one part of the visual field (i.e., central) to another visual field (periphery).

Methods
Design Overview

The design involved a mixed analysis of variance (ANOVA) with bilingual proficiency (balanced vs unbalanced) as the between-groups factor. Type of attention (central, peripheral, switch) was the repeated measures factor. The attention conditions were counterbalanced in terms of order of presentation. From the theory of signal detection (TSD; Swets, 1964), $d'$ provided a measure of sensitivity to visual stimuli in central or peripheral vision. A separate repeated measures ANOVA was conducted with reaction time (RT) as the dependent measure of attention.

Participants

Institutional Review Board approval was obtained from the University of Houston’s Committee for the Protection of Human Subjects. A total of 59 deaf participants were recruited in Texas, New Mexico, and Washington, DC. Nine participants were excluded from data analyses due to videogame experience ($N = 3$), difficulty with visual perception ($N = 1$), inability to complete testing ($N = 1$), reported neurological issues known to affect attention performance ($N = 2$), or late onset of hearing loss beyond 36 months ($N = 2$). All participants had normal or corrected-to-normal vision.

Participants were given objective proficiency testing in English and ASL. Two participants who obtained scores lower than 1 standard deviation (SD) from the group mean on both language tests were removed. Grouping of the remaining 48 eligible participants was based on the following criteria: (a) High proficiency on “both” English and ASL measures as determined by cut-off scores resulted in assignment to the balanced bilingual group ($N = 24$) and (b) high proficiency in one language and low proficiency in another language resulted in assignment to the unbalanced bilingual group ($N = 24$). Participants in both groups had normal or corrected-to-normal vision. There were no age group differences ($t = -0.238; p = .81$). For nonverbal intelligence, the difference ($t = 1.81; p = .08$) was considered to lack significance statistically by conventional criteria. Nevertheless, this variable was entered as a covariate in analyses to control for its potential effect on the outcomes. The two bilingual groups differed on the age of first language acquisition ($t = 2.6; p < .01$) and age of second language acquisition ($t = 2.8; p < .01$). These two covariates were also entered in the analyses. A summary of demographics and language characteristics for each group is provided in Table 1.

Apparatus and Stimuli

Stimulus presentation and recording of responses were controlled by PsyScope software (Cohen, MacWhinney,
Flatt, & Provost, 1993). The stimuli were presented on a 17-inch monitor connected to a PowerBook or iMac, and responses were collected via any key pressed on the keyboard. Each of the attention conditions involved four cross-symbols (+) arranged in a square format in the center and corresponding four cross-symbols in the periphery forming a larger square, with different instructions for each condition. The predetermined number of the four cross-symbol (+) stimuli in the periphery was obtained from the findings of Proksch and Bavelier (2002) regarding deaf participants’ greater allocation of their attention resource to the peripheral visual field at a maintenance load of four compared to six stimuli. Four additional stimuli with an identical cross-symbol (+) shape were also displayed in the foveal region of attention. The participant sat 36 inches from the monitor. The cross symbols for the central attention condition were 1.25 inches from the center, yielding an eccentricity of 2 degrees. The peripheral attention crosses were 3.25 inches from the center, yielding an eccentricity of 5 degrees. The stimulus locations were at angular positions of 60°, 120°, 240°, or 300° from the center of the screen. The cross symbol was either white or black. The background was gray.

A Go-No/Go paradigm was used to develop an attention-switching computer experiment. The Go-No/Go paradigm requires a simple motor response to a target while withholding this response when a target is not present. In its classic form, the Go-No/Go paradigm provides a clean measure of inhibition without additional cognitive processing such as that involved in executive function demands or response selection for two-button (yes/no) choice task (Proctor & Vu, 2003). The one-button response in the Go-No/Go paradigm promotes more accurate responding and reduces additional cognitive (e.g., decision making associated with button pressing) and motor processing that typically emerge in two-button Yes/No paradigm (Perea, Rosa, & Gomez, 2002). The attention conditions in this study were designed to tap two functions: selectively attending to targets among distracters (Go) and inhibiting responses to nontargets (No/Go).

**Materials and Procedure**

Two measures were used to assign deaf participants to language groups and to obtain other demographic and descriptive information. We developed a Demographic Questionnaire to gather self-reported information about the participant’s background that included the etiology of participants’ deafness, early intervention period, language experience, self-rating of parent–child communication fluency level during childhood, handedness, and education history. The Raven’s Standard Progressive Matrices

<table>
<thead>
<tr>
<th>Table 1 Demographics and language characteristics for balanced and unbalanced bilingual groups (N = 48)</th>
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</thead>
<tbody>
<tr>
<td>Balanced bilinguals</td>
</tr>
<tr>
<td>Age of first language acquisition in months*</td>
</tr>
<tr>
<td>English as first language</td>
</tr>
<tr>
<td>ASL as first language</td>
</tr>
<tr>
<td>Age of second language acquisition in years*</td>
</tr>
<tr>
<td>English as second language</td>
</tr>
<tr>
<td>ASL as second language</td>
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<tr>
<td>Age</td>
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<tr>
<td>IQ*</td>
</tr>
<tr>
<td>Ethnicity</td>
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<tr>
<td>Gender</td>
</tr>
<tr>
<td>Etiology</td>
</tr>
<tr>
<td>Genetic</td>
</tr>
<tr>
<td>Nongenetic causes</td>
</tr>
<tr>
<td>Unknown</td>
</tr>
<tr>
<td>Higher proficiency in English and ASL is balanced for this group</td>
</tr>
</tbody>
</table>

*Mean (SD) listed for each variable; N (percentage) is listed for all other variables.
Test (Raven, Raven, & Court, 1998/2003) is a culturally nonspecific, well-validated instrument that provided a valid nonverbal measure of intellectual ability in children, adolescents, and adults (Lezak, 2004).

Two language measures were administered and used for group assignment based on language proficiency in English and ASL. High proficiency for English was defined as a score equivalent to or above Grade 10.5 on the Passage Comprehension subtest (Woodcock & Johnson, 1989). With consultation from an ASL linguist, we developed 30 items that tapped linguistic aspects of ASL syntax. These include negation, wh- and rhetorical questions, yes–no, verb agreement, and number agreement. On this ASL syntax test, the participant was asked to judge if the ASL syntax on video was correct or incorrect. Because there is no objective measure of ASL that has been validated for public use, a self-rating of ASL proficiency developed by the investigator was also administered to all participants and examined for its correlation with objective proficiency test of ASL syntax ($r = .52$, $p < .001$). A composite score was calculated by averaging scores on the objective (ASL test) and the subjective (ASL self-rating) measures. ASL composite scores at the group mean or higher were labeled as highly proficient for ASL fluency. High-proficiency scores on both English and ASL tests were required for a participant to be assigned to the balanced bilingual group. Participants who had ASL composite score that fell below group mean “or” English proficiency score of 10.4 or below were assigned to the unbalanced bilingual group.

Participants were tested individually and typically completed all tasks within 2 hr. The computer attention experiment comprised 600 test trials divided into three blocks (conditions) of 200 trials each with a rest break between each pair of blocks. After instructions were presented on the screen and by the researcher, the participant completed 25 practice trials with feedback and repetition to become familiar with each condition. RT was recorded in milliseconds on all trials, but no feedback was given on test trials.

For the “central” attention condition, the participant was asked to ignore the four distracters in the periphery and attend to the four crosses in the central vision. The participant was instructed to hit the key if exactly “one white” cross appeared in the central vision (target). If not so (nontarget), the participant was asked to refrain from hitting the key. Nontarget included two or more white crosses or no white cross at all.

For the “peripheral” condition, the participant was asked to ignore the distracters in the center and press any key if exactly “one white” cross appeared in peripheral vision (target), and if this was not so (nontarget), refrain from hitting the key. Nontarget included two or more white crosses or no white cross at all. The participant was reminded to fixate eyes on the center while attending to target stimuli in the periphery.

Location of the target within central (or peripheral) vision was randomly distributed across trials. Figure 1 illustrates the event sequence for one trial in central condition. The event sequence for peripheral condition is identical except that the target is located in the periphery region. The response interval was set at 1,200 ms. If the participant saw a target and responded correctly by hitting a key, this was counted as a hit. A false alarm occurred when a nontarget appeared and the participant hit a key. If the target appeared on the screen and the participant failed to hit the key, this was coded as an omission. After the 1,200-ms interval ended, the next trial began.

The attention-switching condition involved two types of cognitive load: switching between targets in the central and peripheral regions over trials and refraining from hitting the key or spacebar when a nontarget stimulus appeared after a repeated sequence of three targets. Participants were asked to hit the key when they saw one white cross-symbol stimulus in “either” central or peripheral visual regions, and do nothing if this was not met (see Figure 2). The switching condition had 200 trials with 150 targets and 50 nontargets. The increased number of targets in the switching condition as compared to central and peripheral conditions was intended to induce a high frontal lobe cognitive load, requiring more cognitive flexibility and readiness to inhibit responses to nontargets after a continuous series of targets (Lavie, Hirst, de Fockert, & Viding, 2004). Flexibility in shifting attention and immediately inhibiting responses under cognitive load in this Go/No-Go paradigm.
are important aspects of higher order attention switching and bilingualism.

Statistical Analyses

A minimum sample size of 44 was required to obtain 95% power to detect a medium effect of Cohen’s $f^2 = .25$ (Cohen, 1977) based on the G*Power analysis program for mixed repeated measure ANOVA (Erdfelder, Faul, & Buchner, 1996).

Simple reaction time methodology was applied to examine the time that it took the participant to view and process visual stimuli in the experiment. The RT value was obtained by calculating number of the milliseconds that it took the participant to hit the key after a target stimulus was presented on the screen. RTs that fell below 200 ms were considered too fast to represent a motor response to the stimulus just presented and were removed from the data set (Posner, 1980). An RT mean and an SD were then calculated for each condition for each participant. Within each participant data set, we dropped trials with RTs that were 2 SD above the mean to eliminate cases in which the participant was distracted from the task at hand (Ratcliff, 1993). From TSD (Swets, 1964), $d'$ was used to assess participants’ selective attention (perceptual sensitivity) to visual stimuli in central and peripheral visual areas. It was based on the data for the remaining trials for each participant after trials were removed for too short and long responses as previously discussed. The number of hits and false alarms for each participant on each condition was converted to probabilities. The standard formula for $d' = [z(\text{probability of hits})] - [z(\text{probability of false alarms})]$ was calculated. A large $d'$ was interpreted as better selective attention (perceptual sensitivity) to visual stimuli in this experiment.

Assumptions were met for the attention data sets (RT and $d'$). Perceptual sensitivity and RT data were then analyzed in two separate repeated measures ANOVAs. No demographic or socioeconomic status variables contributed significantly to the model as covariates and were therefore removed from the analyses. There were also no order effects for attention conditions ($p > .05$). Thus, the data from the different orders were combined for subsequent analyses. We also performed post hoc analysis on balanced bilinguals who acquired their second language prior to or after 7 years of age to indicate the effect for age of second language acquisition on attention switching.

Figure 1  Sequence of event presentation for single-task selective attention condition trial.
Results

Raw attention data for $d'$ and RT mean scores are presented in Table 2. In the RT repeated measure ANOVA, the main effect for attention condition was significant [$F(2, 45) = 10.790, p < .001; \text{partial } \eta^2 = .33$] with faster responses to central stimuli as opposed to peripheral stimuli and switching between these two visual fields. Neither the main effect for bilingual groups ($p > .632$) nor the interaction was significant ($p > .893$).

A similar repeated measures ANOVA conducted on $d'$ data set was conducted. Ages of first and second language acquisition as well as nonverbal intelligence were initially entered into the analysis as covariates but were removed because they did not result in a significant adjustment of the group means. The main effect of attention [$F(2, 45) = 55.248, p < .001; \text{partial } \eta^2 = .71$] was highly significant and represented a large effect size. As with RT data, perceptual sensitivity for central stimuli was higher than peripheral stimuli and switching between these two visual fields. In contrast, there is a significant between-subjects effect [$F(1, 46) = 18.842, p < .001$], which reflects differences in attention conditions. The interaction of attention and bilingual proficiency level was also significant for $d'$ [$F(2, 45) = 5.145, p < .01$].

Specific interaction contrasts were conducted. The first contrast compared the group means of bilingual proficiency for the single task (central condition) with

Table 2  Raw attention data for perceptual sensitivity ($d'$) and reaction time (RT)

<table>
<thead>
<tr>
<th>Data</th>
<th>Bilingual group</th>
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<tbody>
<tr>
<td></td>
<td>Balanced</td>
<td>Unbalanced</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>$SD$</td>
<td>Mean</td>
</tr>
<tr>
<td>Central $d'$</td>
<td>4.23</td>
<td>.88</td>
<td>3.63</td>
</tr>
<tr>
<td>Peripheral $d'$</td>
<td>2.67</td>
<td>1.30</td>
<td>1.68</td>
</tr>
<tr>
<td>Switch $d'$</td>
<td>3.22</td>
<td>1.13</td>
<td>1.56</td>
</tr>
<tr>
<td>Central RT</td>
<td>422.38</td>
<td>58.62</td>
<td>420.22</td>
</tr>
<tr>
<td>Peripheral RT</td>
<td>449.84</td>
<td>61.06</td>
<td>442.93</td>
</tr>
<tr>
<td>Switch RT</td>
<td>460.49</td>
<td>58.29</td>
<td>460.13</td>
</tr>
</tbody>
</table>
another single task (peripheral condition). In the second contrast, these two conditions were merged into one single-task data set. The mean from this single-task performance data set was compared with the mean from dual task (switch condition). This contrast was used to determine the effect of cognitive attention load as the task shifted from selectively attending to targets in a single visual field (single task) to simultaneously attending to targets and switching between visual fields (dual task). The central versus peripheral contrast indicated that both balanced and unbalanced bilingual groups performed similarly on single-task conditions [\( F(1, 46) = 1.157, p = .288 \)]. The contrast for the dual-task condition versus both single-task conditions indicated that there was a significant change in the perceptual sensitivity from single-task attention conditions to dual-task attention condition [\( F(1, 46) = 9.647, p < .003 \)]. This cognitive attention load effect accounted for 17% of the variability in the \( d' \) scores. These results mean that the benefit of higher bilingual proficiency became more effective as the cognitive attention load increased in switch condition.

An analysis of covariance was conducted to assess the effect of bilingual proficiency on shifting attention to one visual field to another visual field (switch condition). Intelligence, age of first language acquisition, and age of second language acquisition covariates did not result in a significant adjustment of the group means and were removed from the model. Results from univariate analysis revealed a large effect of bilingual proficiency on attention switching [\( F(1, 46) = 33.89; p < .0001 \)]. As seen in Figure 3, balanced bilinguals outperformed unbalanced bilinguals on the attention-switching task. Additional post hoc analyses were conducted to examine the role of age of acquisition on attention-switching performance within the balanced bilingual group. The group included 12 early-balanced bilinguals who reported that they acquired both ASL and English prior to age 7 and 12 late-balanced bilinguals who acquired ASL as a second language at or after age 7. Participants whose first language was English reported that they were first exposed to this language through literacy, cued speech, and/or speech reading as an infant. After controlling for age at which the first language was learned, univariate analyses on \( d' \) and RT measures failed to show significance for age of second language acquisition factor [\( d' = F(1, 23) = .291, p > .595 \); RT: \( F(1, 23) = 1.259, p > .275 \)].

**Discussion**

This study examined the effect of bilingual proficiency on performance of a low-level selective attention task within central or peripheral visual regions as well as performance of a high-level attention-switching task between these central and peripheral visual regions. Consistent with our predictions, the balanced bilingual group performed similar to the unbalanced bilingual group on low-level attention tasks. Attention performance on the central visual condition was better across both groups as opposed to attending to peripheral visual stimulus presentation.
The results also confirmed our hypotheses of a high bilingual proficiency advantage on attention-switching task. As predicted, balanced deaf bilinguals exceeded unbalanced deaf bilinguals in their performance when attention switching required one to selectively attend to changing locations of visual targets in the central and peripheral regions while inhibiting responses to distracters. The groups were comparable in the amount of time required to process information and respond to targets.

The findings of this study add to those that have followed a groundbreaking study associating bilingualism with higher order cognitive ability (Peal & Lambert, 1962). Balanced deaf bilinguals are better able to inhibit distracters and successfully deal with changing target locations without getting distracted or derailed. Although all deaf participants in our unbalanced bilingual group had experience with a second language, they did not demonstrate the level of second language fluency that was needed to exploit the benefits of inhibitory control and cognitive shifting ability. The bilingual effect remained strong even after taking into account all demographic, socioeconomic status, and age of first and second language acquisition variables.

To date, there are no published studies that used nonlinguistic cognitive task to compare higher order attention performance between early- and late-balanced bilinguals. In our study, post hoc analyses were conducted within the balanced bilingual group to determine whether the age of acquisition for second language had an effect on attention-switching performance. Researchers argue that individuals who learn a second language after 7 years of age rarely demonstrate native-like fluency compared to those who learn their languages prior to age 7 (see Meisel, 2004, for a review). Thus, a cut-off age of 7 years was used to separate early-balanced bilinguals from late-balanced bilinguals even though all participants did not differ on level of proficiency in both ASL and English. After controlling for effects of intelligence, post hoc analyses failed to detect significant group differences between early- (Languages 1 and 2 < age 7) and late-balanced bilinguals (Language 2 > age 7). This suggests that the age of second language acquisition is not an important factor in examining the effects of bilingualism on attention switching. Rather, it appears to be the level of proficiency in both languages that is the driving force for higher order cognitive flexibility. Given the small sample size for the post hoc analysis on the early- and late-balanced bilingual comparison group and associated low power, further research with additional data is needed to reach conclusive interpretation for the influence of age of second language acquisition on higher order attention-switching ability.

We might have expected to find that the two languages of balanced bilinguals shared the same cortical region if fMRI data were available on our participants thus making available neural resources in the frontal region for processing demanding cognitive tasks. Perani et al. (1998) conducted a functional neuroimaging study with early and late bilinguals who were equally proficient in L2. They did find similar overlapping cortical activations between the early- and late-learner groups. Furthermore, late bilinguals with varying proficiency level showed differential activations in language-related cortical regions, with the most proficient showing greater overlaps with early bilinguals. Thus, the cognitive benefits of becoming bilingual are most likely not rooted in sensorimotor ability. Because of this, later acquisition of a second language can still result in the bilingual proficiency advantage on switching tasks like the ones employed in this study.

Promotion of high proficiency and balanced bilingualism in deaf children’s education may be informed, at least in part, by findings from this study. One possible question to be investigated is whether deaf children’s higher order cognitive abilities will be maximized by learning two languages (e.g., ASL and English) at a very early age as compared to learning one language early and another later. Inclusion of bilingual education in early intervention training and school curriculum with emphasis on attaining high proficiency in both languages may pave the way to strengthen the neural network system for higher order cognitive functions.

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Conflict of Interest

No conflicts of interest were reported.
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References


